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Stiffness and Thermal Analysis of Doubly Curve Sandwich Panel for an Automobile Application

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Abstract

Automotive industry is rapidly going. More and more comforts are being incorporated in a vehicle. On other hand customers have stringent demand of fuel economy, high performance at low cost. In order to have high fuel economy the automotive manufacturers are induced to reduce weight. In this project car body panel is selected as a target weight reduction component. This can be achieved either using high strength low weight material or by using low weight composite sandwich panel. Aluminum composite (Aluminum skin, polyethylene core and epoxy resin) material being light and strong, it is thought as an alternative material. By using this doubly curve sandwich panel, required stiffness can be achieved with reduced thickness and weight. More over this panel prevents the heat flux infiltration and hence improve air conditioner efficiency. Stiffness and thermal analysis of the panel was carried out using Finite Element Solution. Weight reduction 30.55% has been achieved for the same stiffness and 47.73% lesser heat infiltration has been observed than that with Aluminum panel.

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Keywords: Doubly curve, sandwich panel, Stiffness, Infiltration..

Nomenclature

C	Specific Heat (J/Kg K)
E	Young's modules of elasticity (N/mm^2)
H_c	Total crown height (mm)
k	Spherical shell factor
K	Stiffness (N/mm)
L	Length (mm)
L_1	longitudinal length (mm)
L_2	Transverse length (mm)
R	Radius of curvature (mm)
R_1	longitudinal radius (mm)
R_2	longitudinal radius (mm)
T	Thickness (mm)
σ_y	Yield strength (N/mm^2)
σ_u	Ultimate tensile strength (N/mm^2)
μ	Poison's Ratio
λ	Thermal conductivity (W/m K)

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1. Introduction:

The efforts to reduce the component weight go on in almost every branch within the sheet metal and related industries. As far as parts made in steel sheet are concerned, the weight can generally be reduced by replacing the existing material with a

- Thinner steel sheet with higher strength, or
- Thicker aluminium sheet.

In the automotive industry, activities are in progress on a daily basis to reduce the weight by the two means mentioned above, without losses in performance. Similar activities are going on in other sheet metal industries. Of vital importance in most applications are retaining the stiffness, strength and damping of the parts or by improved materials performance. The purpose of this study has been to explore whether the component weight can be reduced by other means than those mentioned above. In many applications, the sheet metal parts do not carry any significant load. These parts provide only a protecting or separating shield. If protection or separation is the function required, it is not always necessary that the part be made of a single sheet metal.

The success of an automobile manufacturer in this decade will be determined by this ability to meet the requirements of the customer. The customer of today requires a quality vehicle in many different forms. The vehicles must be fuel efficient with low emissions, safe, reliable with minimum maintenance, ergonomically designed and aesthetically pleasing. The outer body panel area of the vehicles is a factor in several of these requirements. Body panel can increase fuel economy through weight reduction. This report describes an analytical method to predict the performance of a body panel based on shape and material properties.

1.1. Stiffness

Stiffness is the rigidity of an object, the extent to which it resists deformation in response to an applied force. The complementary concept is flexibility or pliability: the more flexible an object is the less stiff it is.

1.2. Stiffness for doubly curve panel

C.L.alaniz [1-2], Nader Asnafi and David G.Adams [3] investigate of double curve body Panel stiffness using spherical shell theory as shown in Fig 1.Also panel stiffness is function of following parameters [2].

- Panel size
- Panel curvature
- Panel thickness
- Panel support system(boundary condition)

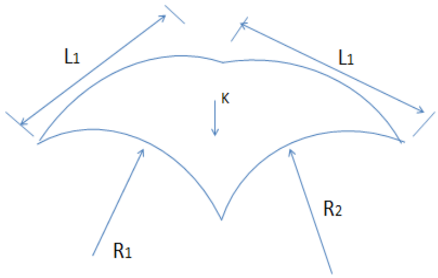


Fig 1. Double curve thin body panel [2]

Also his give imperial stiffness formula based on spherical shell and experimentally as shown in below equation

$$K = \frac{9.237\, E\, t^2\, H_C\, \pi^2}{k\, L_1\, L_2\, \sqrt{1-\mu^2}} \tag{1}$$

$$H_C = \frac{{L_1}^2}{8R_1} + \frac{{L_2}^2}{8R_2} \tag{2}$$

1.3. Composite (Sandwich panel)

One group of laminated composites used extensively is sandwich composites. Sandwich panels consist of thin facings (also called skin) sandwiching a core. The facings are made of high-strength material, such as steel, and composites such as graphite/epoxy; the core is made of thick and lightweight materials such as foam, cardboard, plywood, etc.

1.4. Material

Aluminum as a skin and polyethylene core material has been selected based on low weight and compare to good strength [4-8]

2. Methodology

In this study sandwich panels were fabricated such that heat flux infiltration can be reduced and better efficiency of air conditioning can be improved. It will result in overall efficiency of an automobile. These panels were analyses for heat flux infiltration and stiffness. A comparison with Al panel has also been made.

2.1. Development of marfoming dies for fabrication of doubly curve panel[9]

A die and punch has been fabricated from babul wood as the total force involved in forming of sandwich panel is very low. Dies from babul wood are stronger, cheaper and light in weight. Polyurethane (PU) foam of 100mm thickness has been used in die cavity. This foam applies pressure on blank material against a punch movement. The punch shape exactly replicates the shape and size of a standard doubly curve panel. The punch is also fabricated from the babul wood as shown in Fig 2.

Fig 2. Wooden die and punch made from babul wood

2.2. FE models for thermal (Heat flux) analysis:

2D surface of sandwich and pure aluminium panel of 1.0mm thickness has been created with the help of pre-processor ⇒ Modelling ⇒ Create ⇒ Area ⇒ Rectangular ⇒ By 2 corner and give dimension of panel as shown in below Fig 3

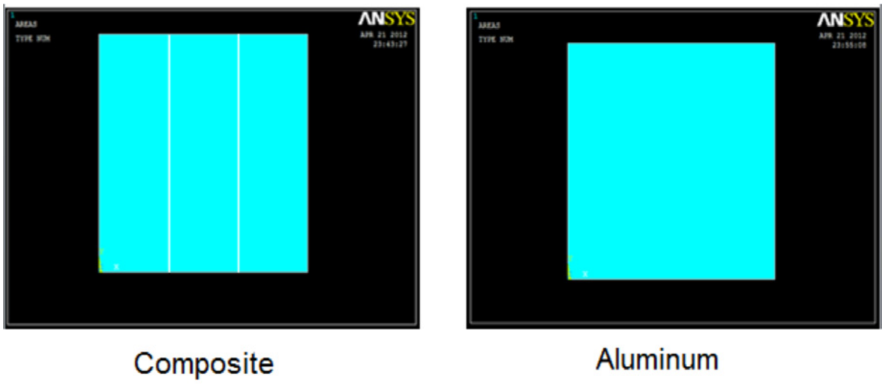


Fig 3. Geometry of panel

Pre-processing for thermal analysis:

After making geometry of sandwich panel and pure aluminium panel in Ansys, next step is inputting element type according to method of analysis. Here for 2D conduction problem PLANE77 8 node thermal solid Element has been selected for thermal analysis. This element does not need any real constant. After selection element type, next is material in put for sandwich panel and pure aluminium panel from Pre-processor ⇒ Material props ⇒ material modes ⇒ thermal ⇒ conductivity ⇒ isentropic ⇒ Kxx (Thermal conductivity of material).Following table shows the materials property used in analysis.

Table 1. Material property use in analysis[11]

Property/Materials	Aluminium	Polyethylene
Density in g/mm^3	2719	940
Specific heat in J/Kg K	871	1550
Thermal conductivity in W/m K	202.4	0.2

Loading and constrain of panel:

According to application of sandwich panel for an automobile body panel following Boundary condition has been considered:
Outer atmospheric temperature: 25 ^{o} C to 30 ^{o} C
Inside front or back bonnet temperature which contains engine: 75 ^{o} C to 80 ^{o} C
After applying all loading and constraining (Inlet temp: 60^o C and outlet temp: 27^o C) Condition to sandwich panel and aluminium panel, solution has been done.

2.3. FE models for model for stiffness analysis:

A standard panel for stiffness test has been modeled using Pro-E software as shown in Figure3.3.The model has been imported to Ansys software for FE simulation. The surface of the sandwich panel has been modeled with SHELL99 element. This element is used for applications of a layered structure shell. SHELL99 allows up to 250 layers. The details of

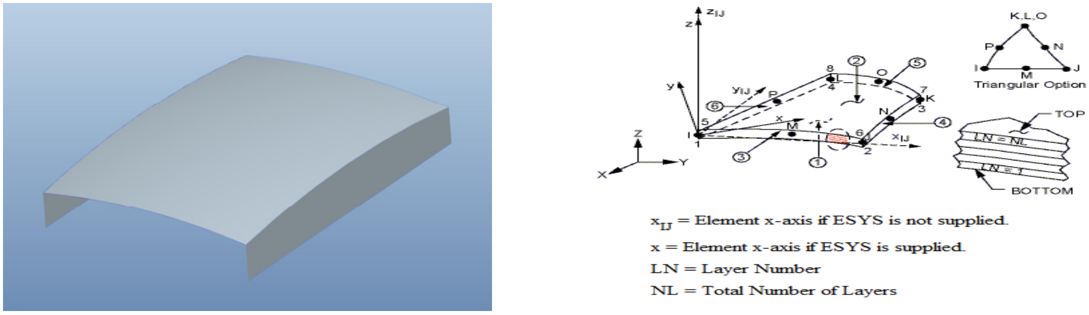


Fig 4. Surface model of doubly curve panel and Structure of SHELL99 Element[10]

The element is shown in Fig 4.The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes.

SHELL99 Input:

Options for SHELL99, Element Type Ref. No. 1	
Form of input K2	Const thk layer
Extra element output K3	No extra output
Element coord sys defined by K4	Elem orientation
Strains or stresses output K5	Stresses only
Extra element output (for layer input only) K6	No extra output
Storage of layer data K8	Bot 1st top last
Eval of strains + stresses K9	Top & bot of lay

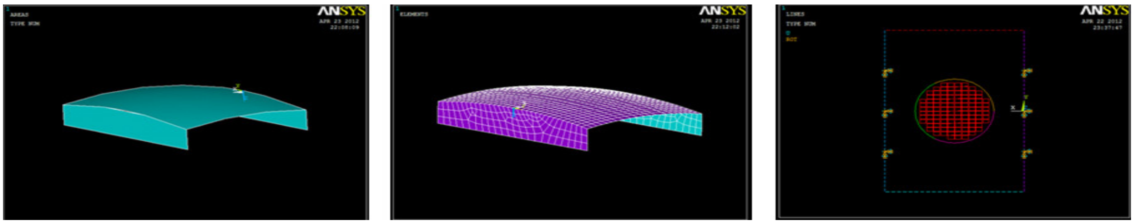
Material prop matrix output K10	Exclude
Node offset option K11	Nodes at midsurf
Real Constant Set No.1	
Element Type Reference No. 1	
Number of layers (250 max) NL	3
Layer Symmetry Key LSYM	0
First layer for output LP1	0
Second layer for output LP2	0
Elastic foundation stiffness EFS	0
Added mass/unit area ADMSUA	0
Mat no., X-axis rotation, layer thk MAT THETA TK	
Layer number 1	1, , 0.35
Layer number 2	2, ,0.3
Layer number 3	1, ,0.35

Table 2. Material property for stiffness test[11]

Material	Poisson's ratio	Young modules in N/mm2	Density in g/mm^3
Aluminum	0.33	69 X 103	2.7 X 10-3
polyethylene	0.29	2.0 X 103	0.940 X 10-3

Boundary conditions:

The force of 130N for stiffness measurement is required to apply at the center of panel within a circular area of 100mm diameter. So, the force has been modeled as a pressure and applied at the nodes within this area as shown in Fig 5 (c).



(a) (b) (c)

Fig 5. (a, b and c) Constraining and loading of panel

2.4. Fabrication of doubly curve panels:

Sandwich panels have been prepared from aluminium sheets of 0.2mm, 0.3mm thickness and polyethylene sheet 0.3mm

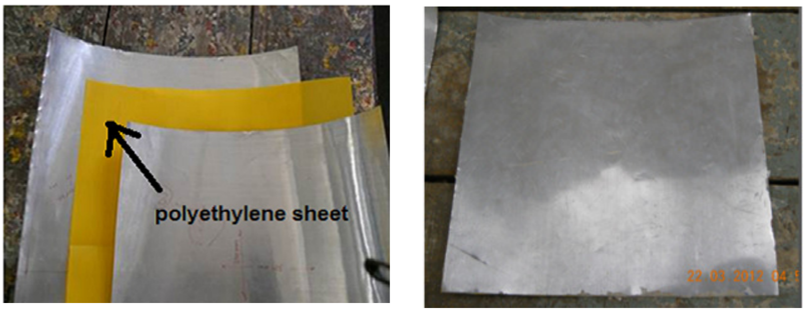


Fig 6. Aluminum and polyethylene sheet

Thickness has been used for manufacturing different sandwich panels. Synthetic resin was used as binder at interface.

Hand layup composite manufacturing process was used to fabricate the panels. The layers of sandwich panel and the at sandwich panel are shown in Fig 6.

2.5. Fabrication of doubly curve shape:

Flat Sandwich panel was pressed between the punch and the PU foam to prepare a doubly curve sandwich panel. A pneumatically controlled 100 ton mechanical press as shown in Fig 7 was employed to apply required forming force. The panels formed from 0.9mm thick aluminium sheet as well as 1.0mm and 0.8mm thick sandwich panels.

Fig 7. Marform setup and doubly curve sandwich panel

2.6. Setup for stiffness measurement:

Plywood sheet fixture with nut and bolt arrangement has been made for constraining doubly curve panels. Pressure applied at centre of panel of 100mm diameter surface as shown in Fig.here wooden wheel of 100mm diameter with negligible weight putted over panel. Over these wooden weed dead weights has been applied as a force. Dial gauges and probe indicators, are instruments used to accurately measure small linear distances, and are frequently used in industrial and mechanical processes. They are named so because the measurement results are displayed in a magnified way by means of a dial. Here accuracy of this dial gauge is 0.01mm.

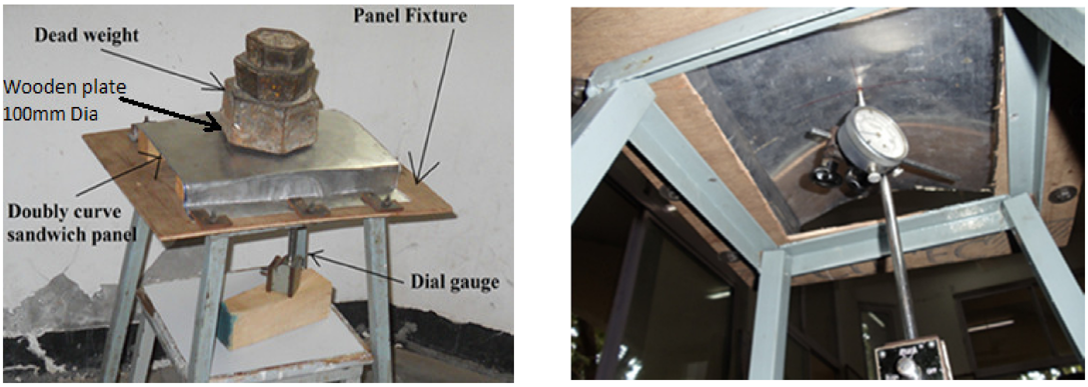
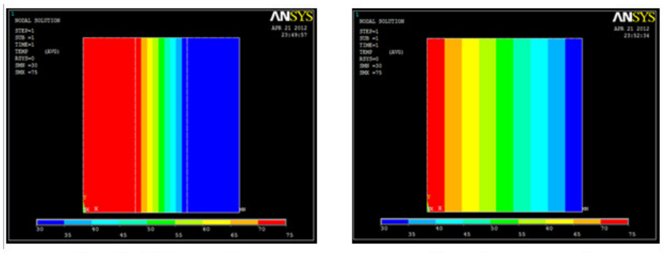


Fig 8. Stiffness test setup

3. Results and Discussion:

3.1. Thermal analysis of sandwich panel:

Thermal analysis of sandwich panel: The temperature boundary condition was imposed on both the side of the panels.330K and 300K temp was imposed on the nodes on left hand side and right hand side respectively. The whole model was considered as one dimensional heat flow model. Thermal analysis of sandwich panel was carried out with the FE simulation. The primary entrust of FE analysis was to find out infill ration of heat flux from one side to another side. In other word the insulation characteristics of the sandwich panel were studies [12].

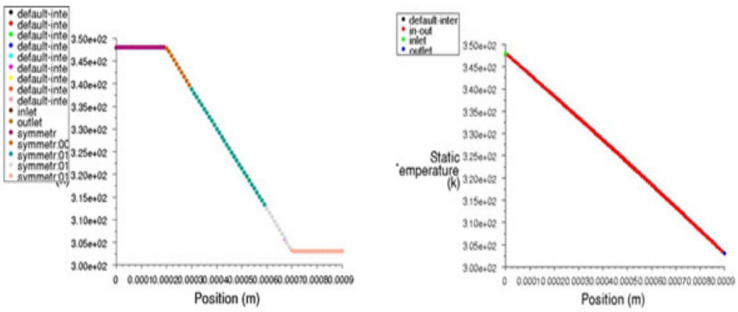


Sandwich panel Aluminum panel

Fig 9. Flow of Temperature along Thickness wise of Sandwich Panel and Aluminum Panel

Fig 10. Selected Noads along Thickness wise

By taking temperature of following node plot graph of Temperature Vs thickness of sandwich and pure Aluminium panel.



Sandwich panel Aluminum panel

Fig 11. Temperature Vs Thickness graph for both panels

Graph Fig 11. That the temperature flow according to thickness wise in sandwich panel and pure aluminium panel.

Comparison of heat flux through the panels:

Table 3. Net Heat in Panels

	Heat flux in sandwich panel	Heat flux in aluminium panel
Net heat flux in W/m^2	677.78898	1418.6807

From FEA simulation it has been observed that the heat flux passing through the sandwich panel is 47.73% that the heat flux passes through Al panel. This can be attributed to the insulation properties of PE sheet in the sandwich panel.

3.2. Stiffness analysis of doubly curve sandwich panel:

Analysis by FE simulation:

Stiffness analysis through FE simulation: Fig 12 shows simulation von Misses stress in sandwich panel. Similarly for Polyethylene sheet and pure aluminium sheet simulation has been carried out.

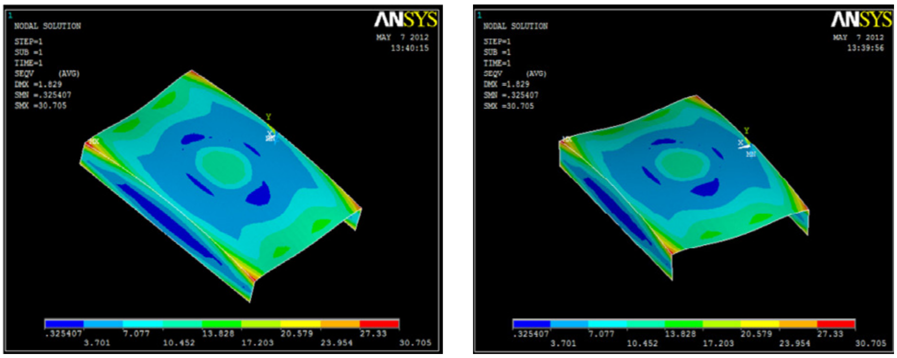


Fig 12. von Misses stress in sandwich panel

Table 4. Sandwich Panel with different Skin and Core materials

Al Thickness (mm)	PE Thickness (mm)	Total panel Thickness [2(Al)+P_e] mm	Volume in (mm^3)	
			V_{Al}	V_{PE}
0.1	0.3	0.5	15180	22770
0.2	0.3	0.7	30360	22770
0.2	0.35	0.75	30360	26565
0.25	0.35	0.85	37950	26565
0.3	0.35	0.95	45540	26565
0.35	0.3	1	53130	22770
0.4	0.35	1.15	60720	26565
0.45	0.35	1.25	68310	26565

After simulation of above thickness sandwich panel following Stiffness results has been found

Table 5. Simulated Panel Deflection and Stiffness at 130 N force

Total panel Thickness	Deflection (simulation)In mm	Stiffness (N/mm)	Stress (Simulation) MPa	
			Max	Min
0.5	18.853	6.7458	168.62	0.5865
0.7	6.028	20.73656	72.423	0.2754
0.75	5.059	24.7084	64.64	0.3535
0.85	3.387	36.9058	48.405	3.387
0.95	2.393	52.23568	38.191	0.3486
1	2.088	64.74	35.006	0.3151
1.15	1.333	93.7734	25.868	0.3403
1.25	1.035	120.7729	21.88	0.3290

Table 6. Comparison for 1 mm Thickness Panel

Material	Thickness	Volume mm^3	Weight (gram)	Deflection (simulation)	Stiffness (N/mm)
Aluminium	1	75900	204.93	1.81	69.06
Poly ethylene	1	75900	71.346	42.3	2.9556
Composite pane	1	75900	144.3618	2.088	64.74

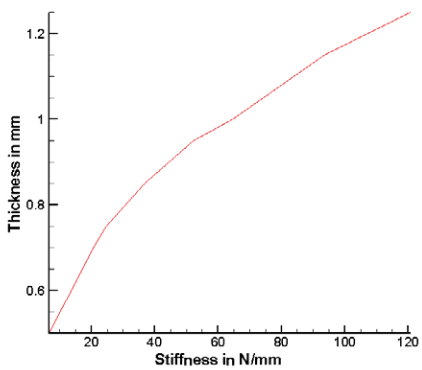
Experimental stiffness analysis:

Standard size panels for stiffness analysis were fabricated. Al panel of 1mm thickness was fabricated and tested for stiffness characteristics for validation of simulation results. Similarly sandwich panels with different skin and core thickness and total thickness were decided such that it will render .The force was gradually increased from 10N to 130N. Similarly sandwich panel (1mm thickness) was also tested for stiffness.

Table 7. Deflection of Panels at Load 10 N to 130 N

Applied load in N	Deflection of aluminium panel In mm	Deflection of composite panel in mm
10	0.1463	0.16059
20	0.2928	0.32118
50	0.7321	0.80297
100	1.464	1.606
120	1.757	1.606
130	1.903	2.088

Results graph for 1mm thick sandwich panel:



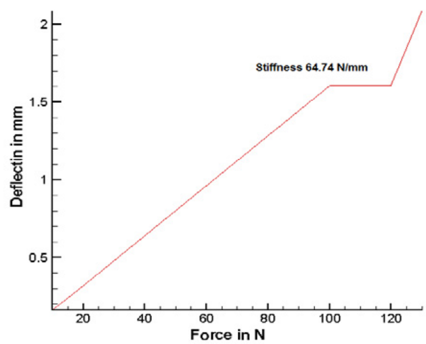


Fig 13. Thickness Vs Stiffness Graph Based on Results Fond in Table 5 And Deflection Vs Force Graph Based on Results Fond in Table 7

Experimental stiffness for sandwich and aluminium panels:

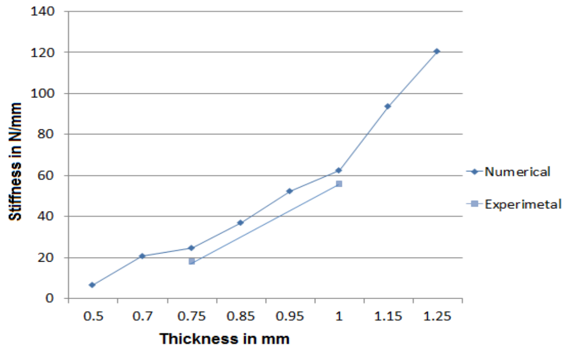


Fig 14. Stiffness Vs Thickness Graph Based on Results Found Comparison of Stiffness and Weight Experimentally and Numerically for 1 mm sandwich panel

Table 8. Experimental Stiffness of Panels at 130 N forces

Thickness in mm	Stiffness (FEA) N/mm	Stiffness (Experimental) N/mm	Weight in gm
Aluminium panel	69.06	73.63	204.93
Sandwich panel	64.74	55.81	144.36

Above table shows comparison of stiffness and weight of both panels. For same stiffness of aluminium panel and sandwich panel weight has been reduce 30.55%.

4. Conclusion

- Punch and Die setup has been developed to form doubly curve sandwich panel successfully.
- Experimental and analytical stiffness analysis has been performed for double curve sandwich panel and it is found that the weight obtained for sandwich panel is lower than pure aluminum panel for same stiffness with 30.55% weight reduction.
- Thermal analysis has been performed for sandwich panel and it has been found that thermal insulation of sandwich panel is greater than pure aluminum panel and the value of heat flux infiltration in aluminum panel is 47.73% more as compare to sandwich panel.

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